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ORDNANCE RESEARCH LABORATORY
The Pennsylvania State University
College of Engineering and Architecture
University Park, Pennsylvania

NAVY DEPARTMENT BUREAU OF NAVAL WEAPONS CONTRACT NORD 16597

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SURFACE REVERBERATION CORRECTION DUE TO A NONISOVELOCITY MEDIUM.

10 by R. E. Zindler

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Reference: (a) ORL Unclassified Technical Memorandum, "A Differential Equation Governing Sound Raypath Intensity," R. E. Zindler, TM 26.2000-43, dated April 7, 1961.

Abstract: Equation (9) provides an approximate equation for the correction of the computation of surface reverberation, as computed for isovelocity waters. The three corrections are termed: a refractive loss correction, a graze angle correction, and a pattern correction.

* * * * *

What correction should be made to a calculated value of surface reverberation that is valid in isovelocity waters in order that it apply to nonisovelocity waters? A two part correction seems in order: One for the transmission loss from the transducer to the surface and return (as this differs in isovelocity and nonisovelocity waters), and one for the pattern (as ray bending in nonisovelocity waters will alter the initial ray angle to the surface). These two are noted in Figure 1.

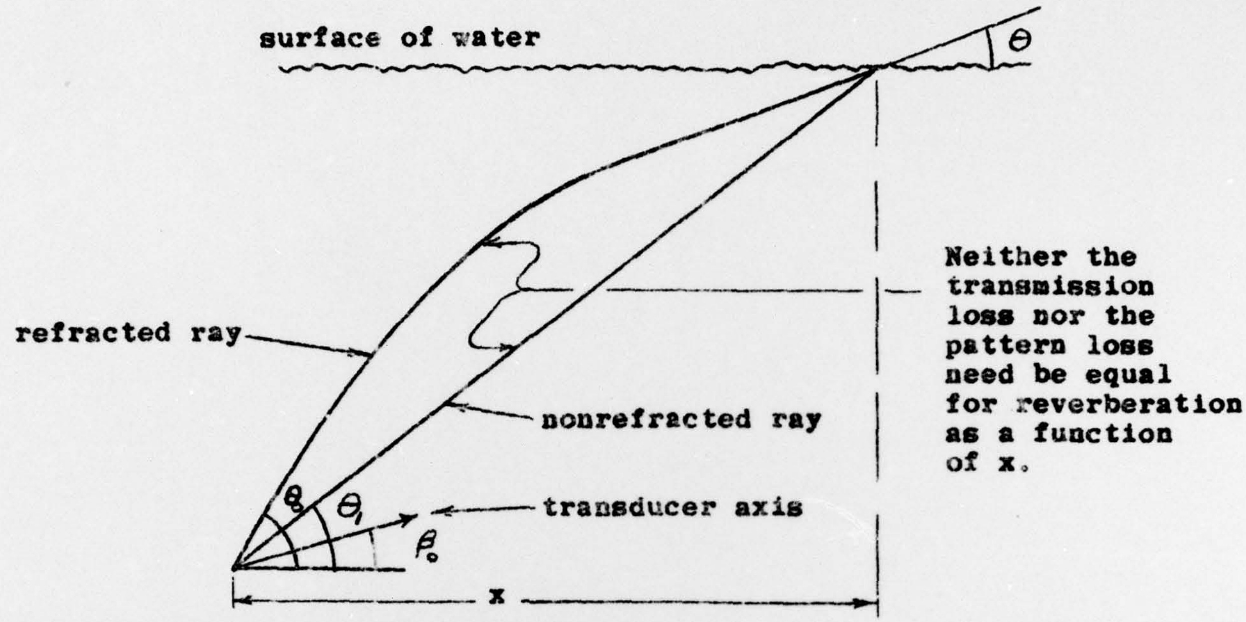

Figure 1

Refracted and Nonrefracted Ray Geometry

Defining the surface reverberation function as being R_s (db) for the corrected form and R_s' (db) the uncorrected (i.e., isovelocity water) form, then two correction factors, ρ_1 and ρ_2, are wanted such that equation (1) holds,

$$R_s = 10 \log \rho_1 \rho_2 + R_s' \qquad (1)$$

If ρ_2 represents the pattern correction term, then it is evidently equal to

$$10 \log \rho_2 = 2 \left[\text{Patt } (\beta_0 - \theta_0) - \text{Patt } (\beta_0 - \theta_1) \right] \qquad (2)$$

where the pattern function, Patt, is symmetric about the angle β_0 in the vertical plane and represents the pattern effect in the usual db nomenclature. (I.e., the peak pattern response is 0 db; the pattern function gives the intensity loss relative to the peak as a function of the angle in the vertical plane). The factor of 2 accounts for two way transmission of the reverberation signal.

The factor ρ_1, likewise needs to be calculated both for transmission and return, i.e., ρ_{1t} and ρ_{1r}. For transmission, the geometry in Figure 2 applies.

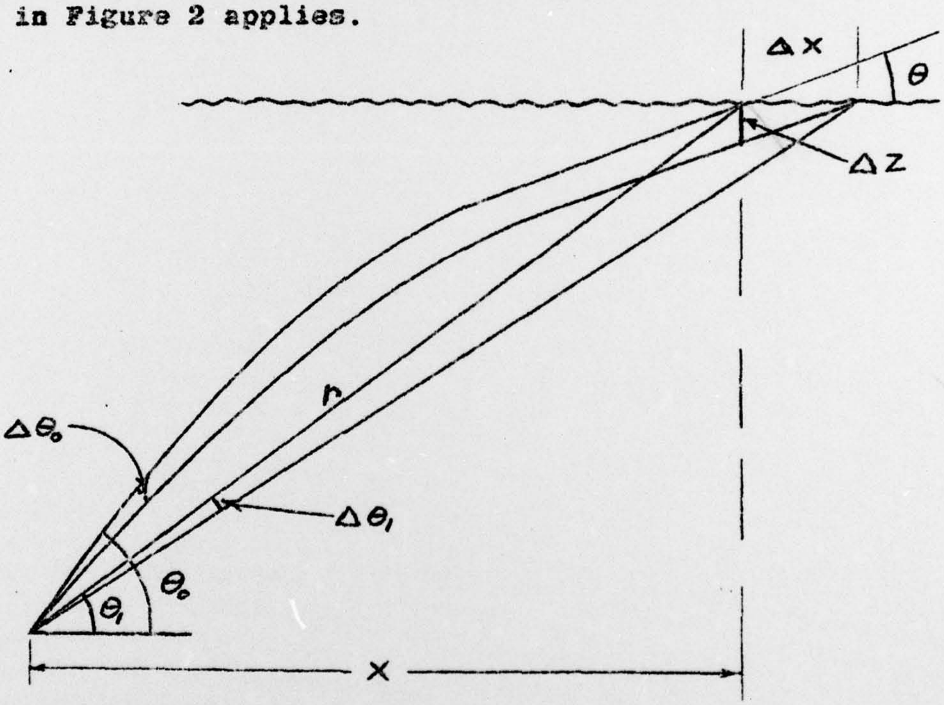

Figure 2

Change due to Refraction Loss on Transmission for a Common Increment Along the Surface

The equation for the refractive loss factor on transmission in terms of Figure 2 is

$$\rho_{1t} = \lim_{\Delta\theta_0 \to 0} \frac{\Delta\theta_0}{\Delta\theta_1} \qquad (3)$$

Equation (3) implies that the transmission loss correction is proportional to the ratio of the amount of energy reaching a small increment of length (Δx) along the surface by the refracted path and nonrefracted path. The concept is analogous to geometrical divergence. The evaluation of the limit is:

$$\rho_{1t} = \lim_{\Delta\theta_0 \to 0} \frac{\Delta\theta_0}{\Delta z} \frac{\Delta z \; r}{\Delta x \sin\theta_1} \qquad \Delta\theta_1 = \frac{\Delta x \sin\theta_1}{r}$$

$$= \lim_{\Delta\theta_0 \to 0} \frac{\Delta\theta_0}{\Delta z} \frac{x \tan\theta}{\sin\theta_1 \cos\theta_1} \qquad \left.\begin{matrix} \frac{\Delta z}{\Delta x} = \tan\theta \\ r = \frac{x}{\cos\theta_1} \end{matrix}\right\}$$

$$= \lim_{\Delta\theta_0 \to 0} \frac{x}{\frac{\Delta z}{\Delta\theta_0} \cos\theta \cos\theta_0} \frac{\sin\theta \cos\theta_0}{\sin\theta_1 \cos\theta_1} \qquad \text{\} rearranging}$$

Since the notation of this memorandum corresponds to that of reference (a) with respect to the refracted rays, it is evident that

$$\lim_{\Delta\theta_0 \to 0} \frac{\Delta z}{\Delta\theta_0} = \frac{\partial z}{\partial\theta_0}$$

and

$$X = \frac{\partial z}{\partial\theta_0} \cos\theta \cos\theta_0$$

and, therefore,

$$\rho_{1t} = \frac{x}{X} \frac{\sin\theta}{\sin\theta_1} \frac{\cos\theta_0}{\cos\theta_1} \tag{4}$$

The variable X can be described as the "refracted x-variable" in the sense that it substitutes for an x in the expression for intensity, I:

$$I = \frac{P \cos^2\theta_0}{x X} \qquad \text{refracted rays,}$$

$$I = \frac{P \cos^2 \theta_0}{x^2} \qquad \text{nonrefracted rays,}$$

where the above hold for one way divergence loss and the same initial angle, θ_0. Returning to equation (4), for practical purposes, the ratio of the cosines can be dropped and the sines replaced by their arguments yielding:

for all ∠s ?

$$\rho_{1t} \approx \frac{x}{X} \quad \frac{\theta}{\theta_1}$$

Surely valid only for small ∠s.

The ratio for the reverberation return can be formulated in terms of Figure 3 where the picture is conceived of being a return from a point on the surface to a small vertical element of transducer face. The equation analogous to (3) is

$$\rho_{1r} = \lim_{\Delta\theta_0' \to 0} \frac{\Delta\theta_0'}{\Delta\theta_1} \qquad (5)$$

where the vertical increment Δz is common to both angular increments.

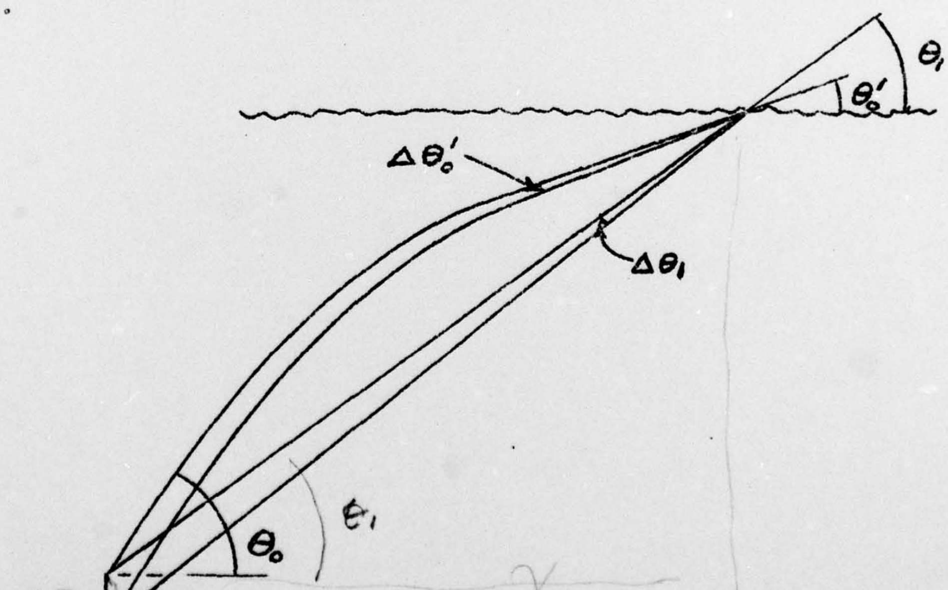

Figure 3
Change due to Refraction Loss on Reception for a Common Increment on the Face of the Transducer

The evaluation of (5) is

$$\Delta\theta_1 = \frac{\Delta Z \cos\theta_1}{r}$$

$$r = \frac{x}{\cos\theta_1}$$

$$\rho_{1r} = \lim_{\Delta\theta_0' \to 0} \frac{x}{\cos^2\theta_1} \frac{\Delta\theta_0'}{\Delta z}$$

$$= \lim_{\Delta\theta_0' \to 0} \frac{x}{\frac{\Delta z}{\Delta\theta_0'} \cos\theta_0' \cos\theta_0} \times \frac{\cos\theta_0' \cos\theta_0}{\cos^2\theta_1}$$

$$\rho_{1r} = \frac{x}{X'} \frac{\cos\theta_0' \cos\theta_0}{\cos^2\theta_1} \tag{6}$$

where θ_0' plays the role of the initial angle and θ_0 the angle at the receiver. The notation X' is used to contrast with X where the former is the "refracted x-variable" on return and the latter is the "refracted x-variable" on transmission. For practical purposes, the cosine ratios could be dropped.

Combining equations (4) and (6) by multiplication gives the correction factor ρ_1:

$$\rho_1 = \frac{x^2}{XX'} \frac{\sin\theta}{\sin\theta_1} \frac{\cos\theta_0' \cdot \cos^2\theta_0}{\cos^3\theta_1} \tag{7}$$

Equations (1), (2), and (7) combine as

$$R_s = R_s' + 10 \log \left[\frac{x^2}{XX'} \frac{\sin\theta}{\sin\theta_1} \frac{\cos\theta \cos^2\theta_0}{\cos^3\theta_1} \right]$$

$$+ 2 \left[\text{Patt}\,(\beta_0 - \theta_0) - \text{Patt}\,(\beta_0 - \theta_1) \right] \tag{8}$$

omit for omni directional source & receiver.

where the notation of θ_0° has been dropped in favor of θ to make the angle notation consistent with Figure 1. For practical computations, equation (8) can be simplified by the following means:

(a) Neglect the cosine ratios,
(b) Replace sine of the argument by the argument,
(c) Assume $X = X'$.

why small?

(a) and (b) can be justified on the basis of the smallness and nearness of the angles involved. Condition (c) is usually assumed and can readily be verified when

$$\frac{1}{V}\,\frac{d^2V}{dz^2} = \text{const}$$

as such implies that the "refracted x-variable" is dependent on the x distance but not on the particular ray traveled to that distance. Making the simplifications, the equation reduces to

$$
\begin{aligned}
R_s \cong\ & R_s' && \text{(computed for isovelocity waters)} \quad (9) \\
& + 10 \log\left(\frac{x}{X}\right)^2 && \text{(refraction loss correction)} \\
& + 10 \log \frac{\theta}{\theta_1} && \text{(graze angle correction)} \\
& + 2 \left[\text{Patt } (\beta_0 - \theta_0) - \text{Patt } (\beta_0 - \theta_1) \right] && \\
& && \text{(pattern correction)}
\end{aligned}
$$

for small grazing LS

Of the terms, only the graze angle correction might be unexpected. The refractive loss correction can easily be shown to approximate the difference between the 2 way intensity loss (a negative number of db) in the refractive medium minus the two way intensity loss (also a negative number of db) in the nonrefractive medium.